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Raman spectra have been obtained from fused silica optical fibers under high reversible torsion. These results are compared to Raman results from fused silica, irreversibly compacted to 90 kbar. An interpretation is presented which suggests a negative correlation between the mean Si-O-Si bridging angle and the mean Si-O distance, plus a negative correlation between the mean Si-O-Si bridging angle and the mean tilt angle between SiO_4 tetrahedra.

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"Raman Investigation Of The Effects Of Torsion On Fused Silica Optical Fibers"

by

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The application of reversible tensile stress (3.3 GPa) to a pure fused silica optical fiber has been found to produce a significant modification of the Raman spectrum.[1] Other Raman changes due to irreversible uniaxial compaction (9 GPa),[2] and reversible hydrostatic compression (1 GPa),[3] were uncovered recently. The present work constitutes a continuation of such studies in which Raman changes due to reversible torsion on a fused silica optical fiber (at constant load) are described and compared to new Raman results[4] from irreversibly compacted fused silica.

The application of reversible torsion to a horizontal fiber involved twisting one end, while the other end was rotationally immobilized just after passing over a vertical pulley. A constant downward force (load) was exerted by a weight attached to the fiber below the pulley. A 3.7 m section of a silicone clad pure fused silica fiber (4.5 m total length) was twisted 515 times before failure,[5] corresponding to 501 degree/cm or 8.75 radian/cm. The resulting spectrum is shown in fig. 1(b).

Comparison of the untwisted fiber spectrum, 1(a), to that of the twisted fiber, 1(b), indicates that one significant Raman change due to torsion involves a loss of intensity between 0-450 cm^{-1}. This result is evident from the $\sim$16 cm^{-1} half-width decrease shown, and by the difference spectrum (inset, upper left).

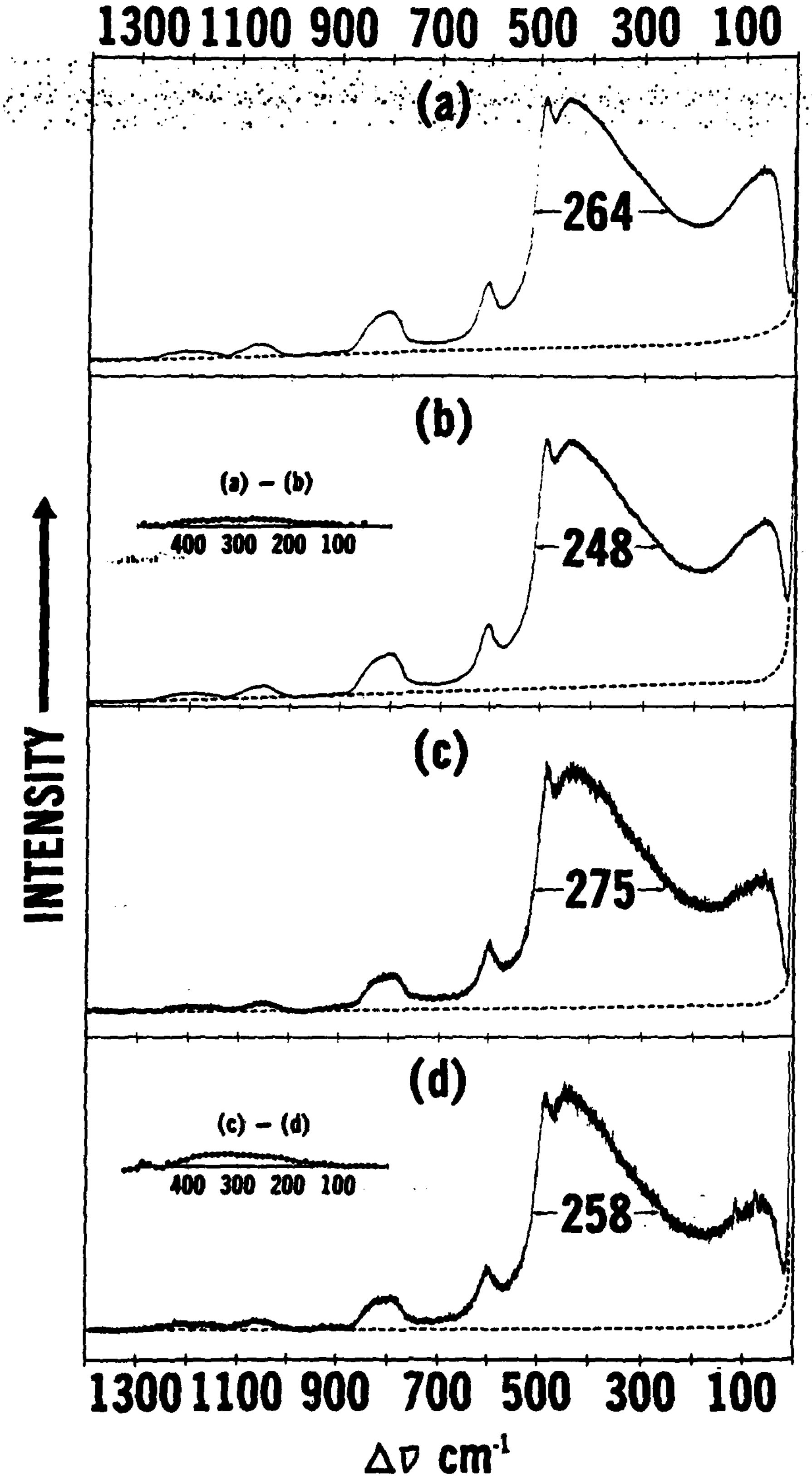
Other Raman modifications similar to those of torsion are evident from spectra of uncompacted (parent) and irreversibly compacted (9 GPa) fused silica, figs. 1(c) and 1(d), respectively.[2,4] Here, the half-width decreases $\sim$17 cm^{-1}, and the difference spectrum (inset, lower left) is also similar to the one above.

Close examination of the two difference spectra, however, indicates that they are not quite identical. The lower spectrum peaks at a higher frequency, $\sim$350 cm^{-1}, and a <u>decrease</u> in the intensity of the "defect" peak[6] at 490 cm^{-1} is apparent-an effect not previously detected under lower S/N.[2] But measurements involving several spectra from twisted and untwisted fibers show that a similar, but smaller, intensity decrease at 490 cm^{-1} also occurs.

From all of the Raman spectral modifications examined for reversible tensile stress,[1] irreversible uniaxial compaction,[2] reversible hydrostatic compression,[3] and irreversible neutron compaction[7] it appears that densification <u>decreases</u> the Raman intensity between 0-450 cm^{-1}. Generalizations including the 490 and 605 cm^{-1} "defect" peaks are harder to make. But an increase of intensity between 0-450 cm^{-1}, and an intensity increase at 490 cm^{-1} were observed for reversible tensile stress, whereas just the opposite effects are now

CAPTION

Figure 1. Raman spectra from untwisted (a) and twisted (b) pure fused silica optical fibers, and from (parent) uncompacted (c) and compacted (9 GPa) bulk fused silica (d). The change in half-width from (a) to (b), 16 cm^{-1}, agrees favorably with the change in half-width from (c) to (d), 17 cm^{-1}, but the (a) and (b) half-widths should not be compared to the (c) and (d) half-widths because different samples and conditions were involved.



1300 1100 900 700 500 300 100
(a)
264
(b)
(a) − (b)
400 300 200 100
248
(c)
275
(d)
(c) − (d)
400 300 200 100
258
INTENSITY
1300 1100 900 700 500 300 100
Δν cm⁻¹

found for reversible torsion and irreversible compaction.

Raman intensity changes between 0-450 cm^{-1}, if large, also entail frequency shifts at 800 cm^{-1} and 1060 cm^{-1}. These effects may result from correlation between the mean tilt angle between SiO_4 tetrahedra, $\bar{\delta}$, the mean Si-O-Si bridging angle, $\bar{\varphi}$, and the mean Si-O bond length, $\bar{r}$. For vitreous silica only, we suggest that an increase of $\bar{\delta}$ refers to a decrease of $\bar{\varphi}$ and an increase of $\bar{r}$ (negative correlation between $\bar{\varphi}$ and $\bar{r}$ is well-established for fused silica,[8] and a negative correlation between $\bar{\delta}$ and $\bar{\varphi}$ has been reported for pressurized α-quartz.[9]) The Raman intensity between 0-450 cm^{-1} is further suggested to decrease as $\bar{\delta}$ increases.

For reversible hydrostatic compression[3] and for irreversible neutron compaction,[7] a large loss of Raman intensity between 0-450 cm^{-1} is accompanied by an upward frequency shift at 800 cm^{-1} and by a downward frequency shift at 1060 cm^{-1}. With decreasing φ, an increase in the Si-O-Si bending force constant is thought to move the 800 cm^{-1} peak upward in frequency,[7] and a decrease in the Si-O stretching force constant due to an increase in r is thought to move the 1060 cm^{-1} peak position downward.

From the correlations now suggested, namely, that increasing $\bar{\delta}$ refers to a decrease in the Raman intensity between 0-450 cm^{-1}, I_{0-450}, as well as an upward shift at 800 cm^{-1} (increasing $\Delta\bar{\nu}$) and a downward shift at 1060 cm^{-1} (decreasing $\Delta\bar{\nu}$), a table may be constructed involving tension, the three compressions, and torsion. Missing entries refer to frequency shifts at 800 or 1060 cm^{-1} which are presently undetectable because they scale with the small Raman intensity changes between 0-450 cm^{-1}. Nevertheless, this table suggests that $\bar{\delta}$ decreases with tensile stress,[1] whereas $\bar{\delta}$ is suggested to increase for the three compressive cases,[2],[3],[7] and also for reversible torsion.

A more detailed interpretation involving Gausssian deconvolution[11] of the 0-450 cm^{-1} region will appear subsequently.

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(4) Scrambled laser polarization was used prior to Raman excitation, Figs. 1(c) and 1(d), to counteract effects of inhomogeneities (cracks) in the compacted sample.

(5) Further rotation caused a uniform pulverization of the fiber over the entire twisted region.

(6) The "defect" peaks at 490 and 605 cm^{-1} have recently been reassigned, A. K. Revesz and G. E. Walrafen, J. Noncryst. Solids (in press).

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